



On-Orbit Propulsion System Project Overview

Presented at

**1st AIAA/IAF Symposium on Future Reusable
Launch Vehicles
Huntsville, Alabama**

April 11-12, 2002



Project Scope



- **The Goal of The Space Launch Initiative Is for NASA to Meet Its Future Space Flight Needs,**
 - Including Human Access to Space, Using Commercial Launch Vehicles That Will Improve Safety and Reliability and Reduce Cost.
- **Dual Thrust RCE APS Program Helps Meet the SLI Objective by:**
 - Reduced Hardware Quantities (Weight/Cost),
 - Reduced Complexity / Cost (Non Toxic Propellants)
- **Reaction Control Engine (RCE) Supports Cross-Cutting Technologies Applicable to Future APS Systems (Auxiliary Propulsion Systems)**
 - Proof of Concept Testing Shows Viability of Dual Thrust RCE



On-Orbit Propulsion Project Purpose



Enable the 2nd Generation RLV Program Technologies through advanced development and risk reduction activities.

Perform advanced development on system elements identified as high risk.

Reduce the risk associated with Auxiliary Propulsion System elements, allowing the Program to enter a system level Full-Scale Development (FSD) phase in 2006.

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On-Orbit Propulsion Project Goals



- Develop APS technologies, reducing risk for candidate Architectures
- Demonstrate significantly improved auxiliary propulsion system safety, operability, and reliability
- Demonstrate operation of Dual Thrust RCS with safe, operable non-toxic propellants
- Reduce the technical and Programmatic risks
- Provide high-fidelity basis for estimates of fight systems dev costs
- Develop and test prototype auxiliary propulsion hardware
- Support the vehicle architecture safety, reliability, and cost goals through the use of non-toxic RCS
- Complete the project on-budget and on-schedule.

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Project Accomplishments

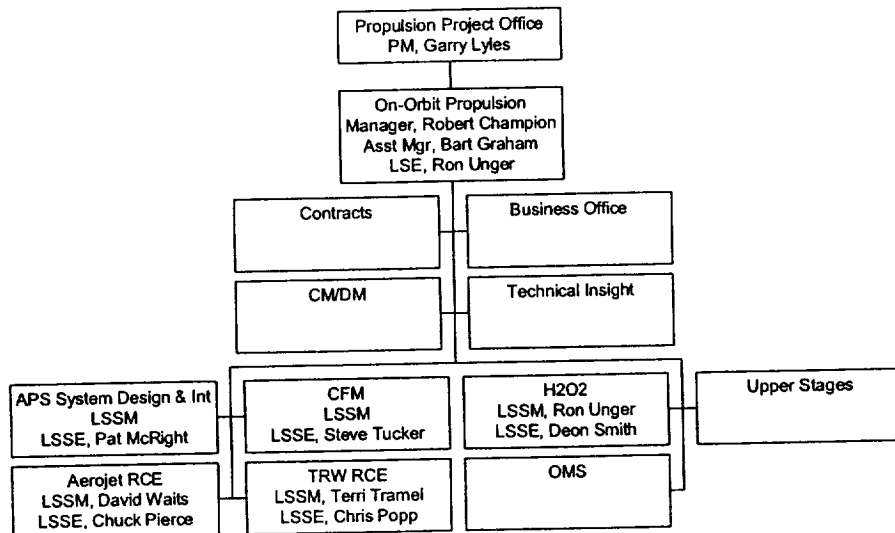


- **Completed Aerojet LOX/Ethanol Vernier Vacuum Testing (12/21/01)**
 - 24 Total: 9 Characterization tests, 10 Steady State tests, 5 Pulse tests
 - 3 configurations
 - 800seconds total burn time and 307 pulses
- **Completed Aerojet Primary Thruster Pulse SS & Testing (1/22/02)**
 - 18 Total: 13 Steady State tests, 5 Pulse tests
 - 4 configurations
 - 300 seconds in Steady State and 1,328 pulses
- **Completed TRW LOX/Ethanol Vernier Testing (1/7/02)**
 - 7 hot fires
 - 1 configurations
 - 1.9 total burn time
- **Initiated TRW LOX/Ethanol Primary Thruster Testing (12/18/01)**
 - 76 hot fires
 - 13 configurations
 - 460 total burn time
- **Completed TRW LOX/LH2 Thruster Primary & Vernier testing at MSFC (4/6/02)**
 - 33 hot fires
 - 8 configurations
 - 350 seconds cumulated burn time
- **Completed Risk Reduction Review for Aerojet, TRW, JSC/WSTF (1/22-23/02)**
- **Completed APS System Requirements Review at WSTF (2/29/02)**

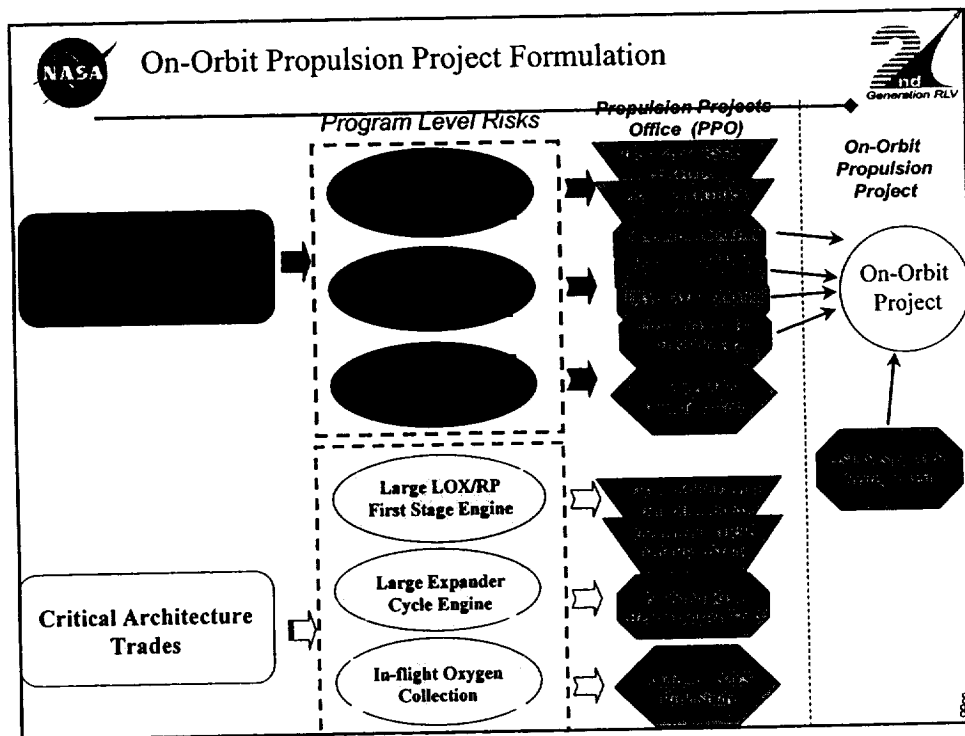
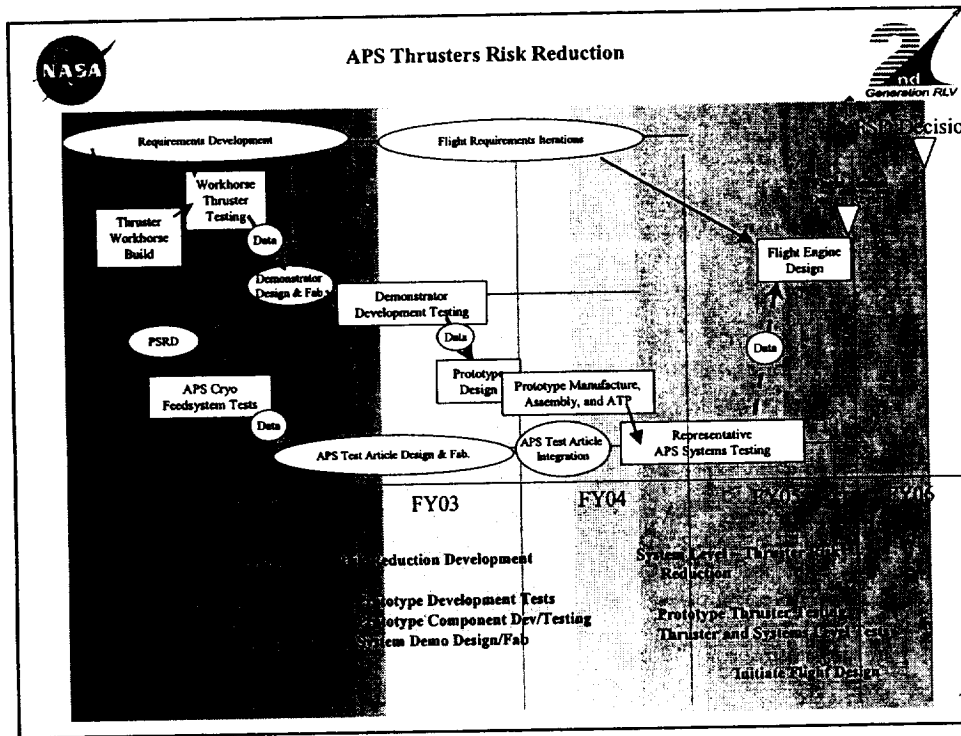
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On-Orbit Propulsion System Project

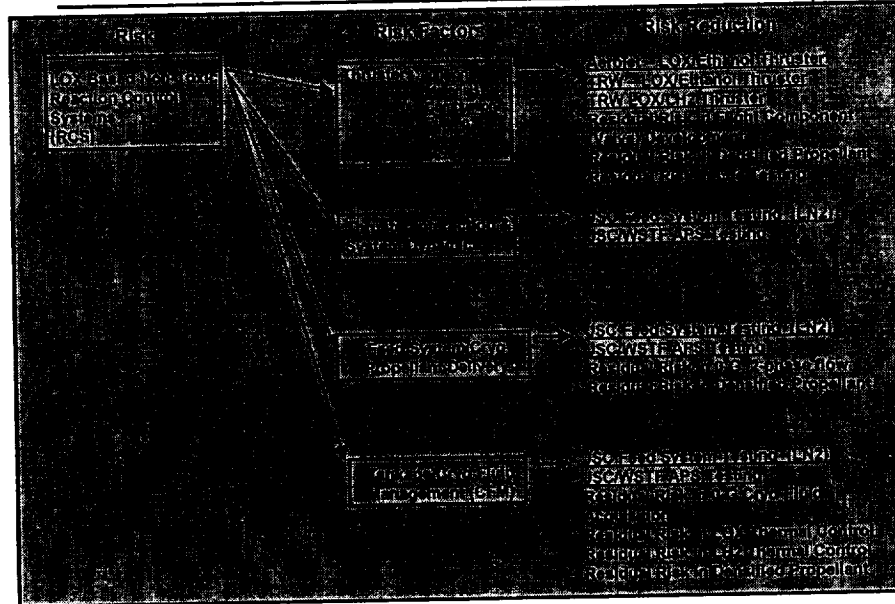


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Project Risk Reduction Activities (APS)



MPS / APS Project: Aerojet APS Thrusters Element



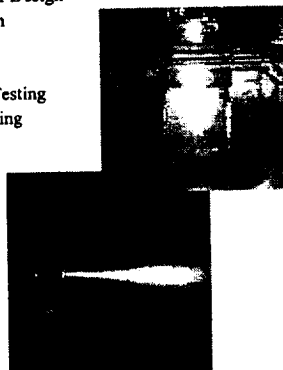
- Task Title: Aerojet LOX/Ethanol Dual Thrust, Thruster Development and Risk Reduction
- Company / Task Manager: Aerojet / Eric Veith
- Government Point of Contact: Robert Champion (PM) / David Waits (SSM)
- Total Program Cost: \$7.608M
- Technical Description:
 - Perform risk reduction activities, relative to the development of an operational non-toxic LOX/Ethanol 870/25 lbf (vacuum) dual-mode thruster, which will achieve a Technical Readiness Level (TRL) 6 by GFY 05.
 - Base Period: Perform Development Testing on the existing Kistler OMS engine
 - Option 1 Period: Perform Dual Thrust Demonstration Testing
 - Option 2 Period: Develop Dual Thrust Engine
 - 3 Dual Mode LOX/Ethanol Engines will be delivered to WSTF for Government-led System Level Testing
- Task Milestones / Products:
 - 10/26/01 Test Readiness Review, Kistler OMS Demo Engine Test
 - 03/13/02 Conceptual Design Review, Dual Thrust Engine
 - 06/24/02 PDR, Dual Thrust Engine
 - 11/07/01 Test Readiness Review, Dual Thrust Engine Test
 - 04/24/02 CDR, Dual Thrust Engine
 - 09/05/02 Test Readiness Review, Dual Thrust Acceptance Test
 - 01/05/03 Deliver Dual Thrust Engines to WSTF



MPS / APS Project: TRW APS Thrusters Element



- Task Title: LOX/Ethanol, LOX/LH2 Dual Thrust, Thruster Development & Risk Reduction
- Company / Task Manager: TRW / Jacky Calvignac
- Government Point of Contact: Robert Champion (PM) / Terri Tramel (SSM)
- Total Program Cost: \$10.887M
- Technical Description:
 - Perform risk reduction activities, relative to the development of an operational non-toxic LOX/Ethanol and LOX/LH2 1000/25 lbf class (vacuum) dual-mode thruster, which will achieve a Technical Readiness Level (TRL) 6 by GFY 05.
 - Base Period: Exploratory Testing, Prototype Design, Igniter/Vernier Design
 - Option 1 Period: Igniter/Vernier Testing, Prototype Detailed Design
 - Option 2 Period: Prototype Acceptance Testing, Flight Design
 - Deliver 3 Dual Thrust LOX/Ethanol Engines to WSTF for System Level Testing
 - Deliver 3 Dual Thrust LOX/LH2 Engines to WSTF for System Level Testing
- Task Milestones / Products:
 - 06/02 PDR, Prototype Engines
 - 05/31/03 CDR, Prototype Engines
 - 03/31/04 Delivery of LOX/Ethanol Engines to WSTF
 - 08/31/05 PDR, Flight Design Engines



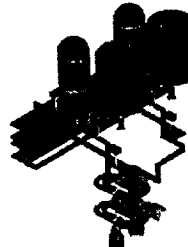
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Integrated Auxiliary Propulsion Systems Test



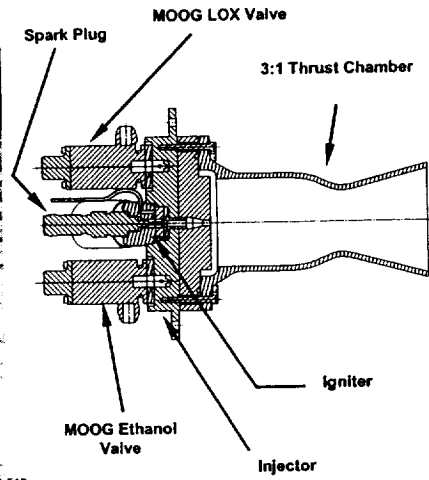
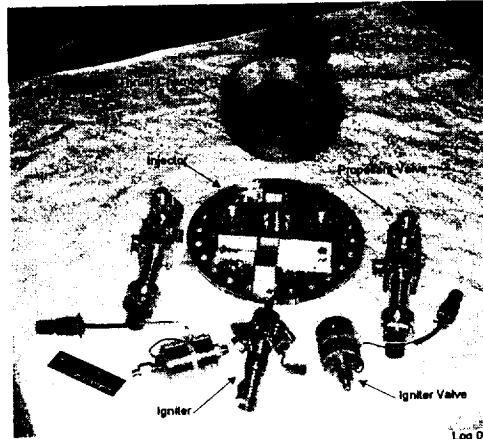
- Task Title: NT APS System Level Test Stand
- Company / Task Manager: JSC / Eric Hurlbert
- Government Point of Contact: Robert Champion (PM) / TBD (SSM)
- Total Program Cost: \$5.713M
- Technical Description:
 - Demonstrate LO2/ethanol engines at the system level in Simulated Space and Ground Processing environment to achieve TRL of 6
 - Test engines at propellant conditions, line diameters, variable line lengths, multiple engines manifolds, instrumentation that are representative of the range of possible systems
 - Provide data for analytical models for line thermal and pressure dynamics to use in FSD
 - Demonstrate Reliable Ignition and operation (goal of 500,000 cycles) under above conditions
 - Demonstrate Automated operation of system and engines in space and ground processing environment
 - Test competing engine designs and provide all data to vehicle primes and system data to engine vendors
- Task Milestones / Products:
 - 2/17/02 Test Plan and Matrix (DE-008) (Draft at ATP)
 - 2/17/02 Test Stand Dynamic Analysis & Models Report- JSC/BNA-Hou
 - 2/17/02 Cryogenic Feedsystem Breadboard Test Report
 - 2/28/02 Test Stand SRR
 - 6/21/02 Test Stand PDR
 - 9/26/02 Test Stand CDR
 - 4/3/03 Receive Test stand hardware (minus engines) and begin assembly and checkout
 - 4/2/04 Test Readiness review
 - 4/1/05 Test reports DE-020



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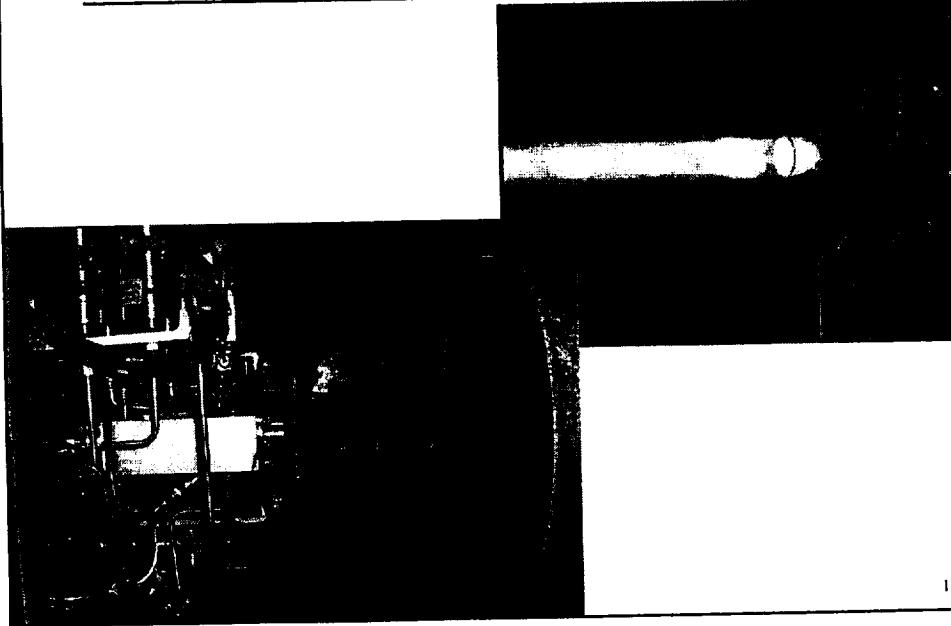
Aerojet LOX/Ethanol Engine



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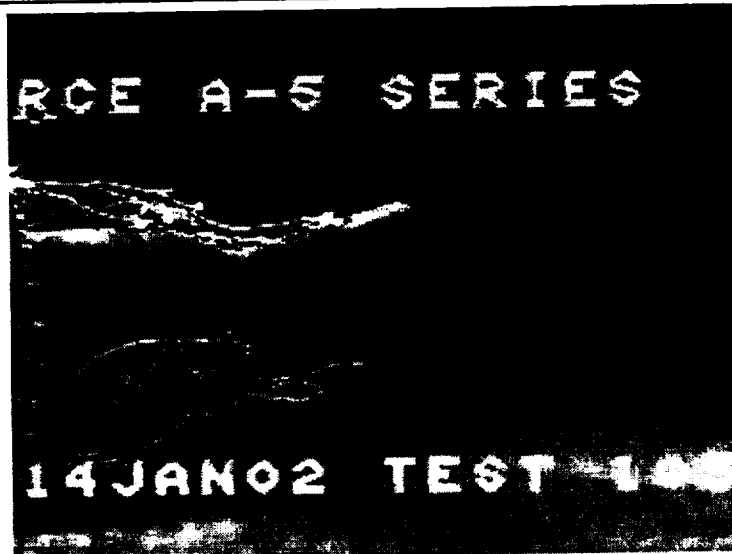
Aerojet Altitude Chamber and Sea Level Test Cell



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Aerojet Has Completed Base Program Test Series

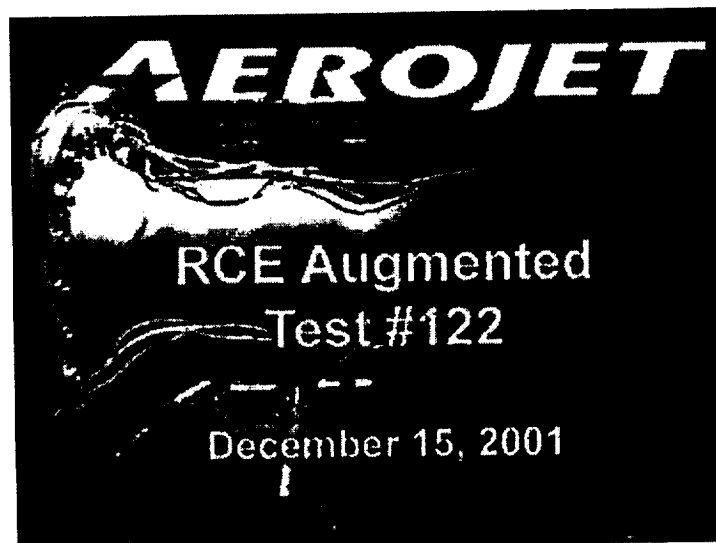


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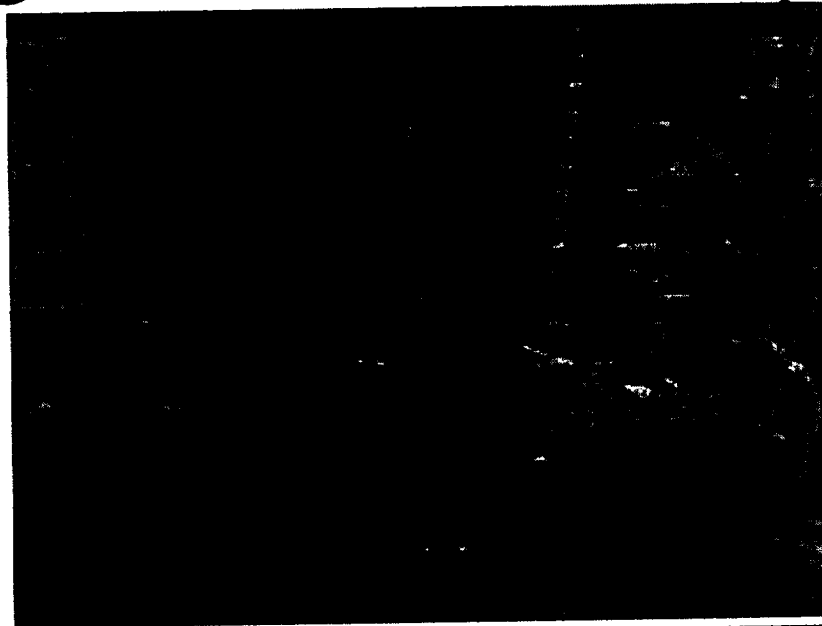
Aerojet RCE Vernier Testing



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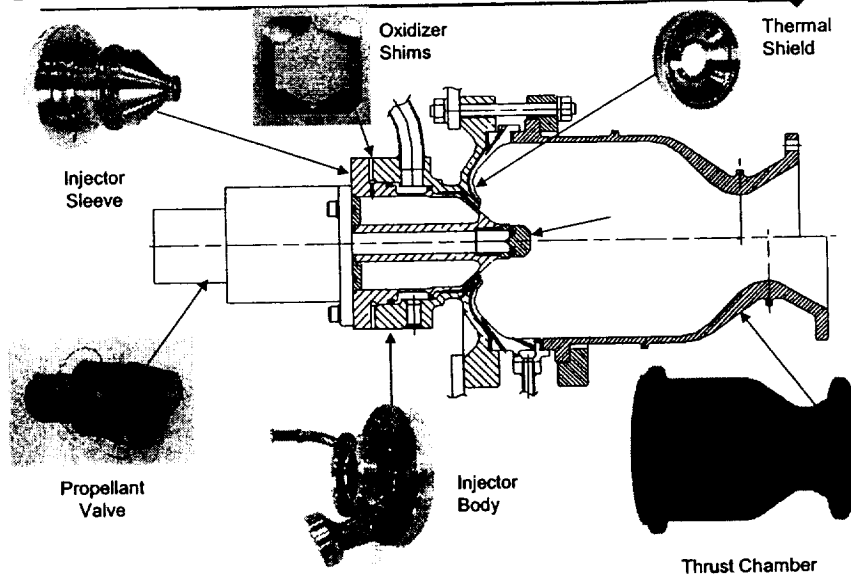
Aerojet RCE Primary Testing



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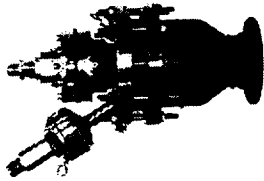
LOX/Ethanol RCS Workhorse Thruster



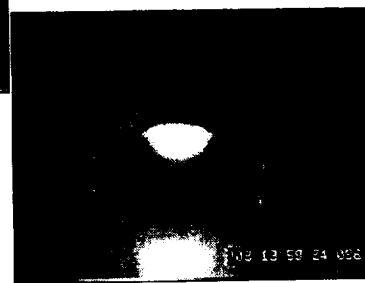
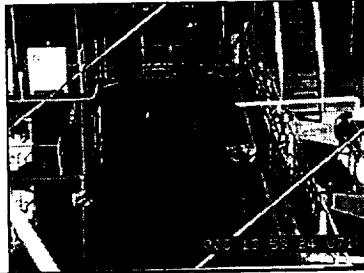
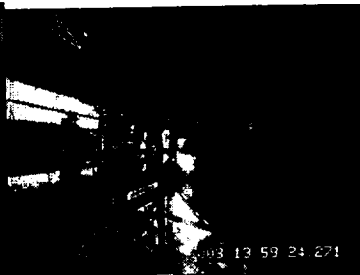
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TRW LOX/Ethanol Thruster Testing



CTS-HB1 Test Position



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Workhorse Thruster Hot Fire Test (5 seconds)



Test HB1-2545
January 8, 2002

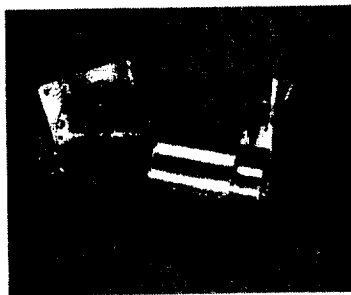
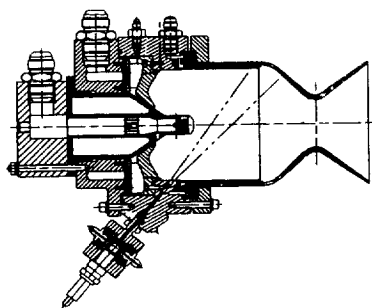
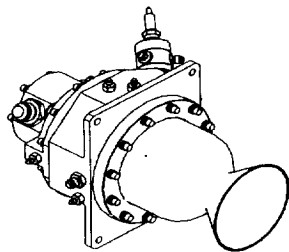
Lower Thrust View

008 13 59 14 535

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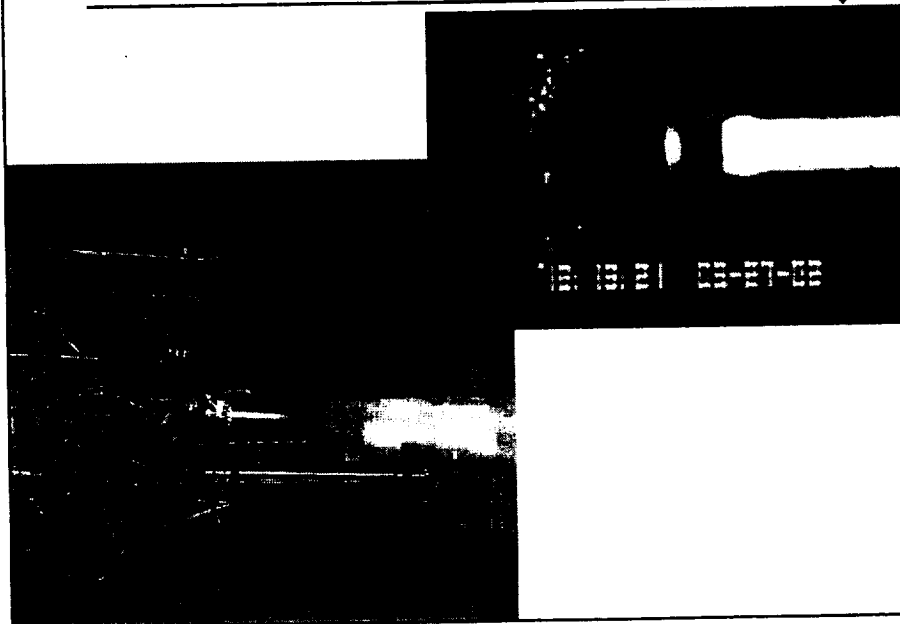
TRW LOX/LH₂ RCS Workhorse Thruster



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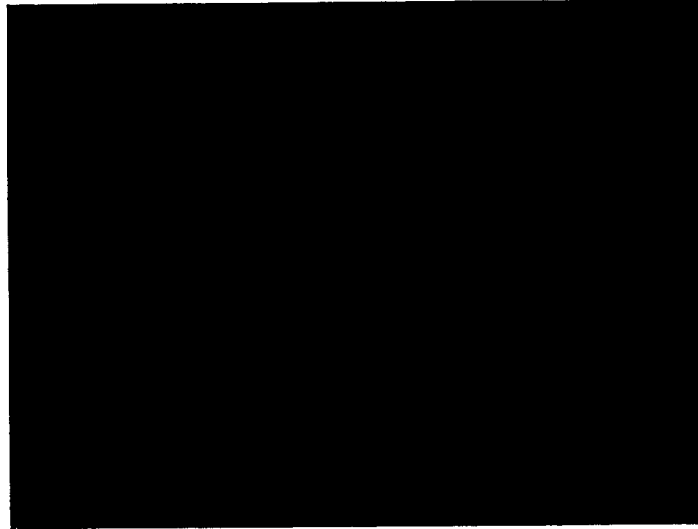
TRW LOX/LH₂ Testing at MSFC



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TRW LOX/LH2 Testing at MSFC



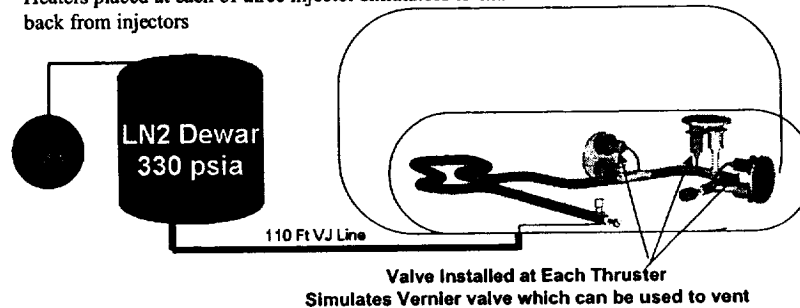
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JSC Cryo Feedsystem Vacuum Test Article



- Configuration will vent warm gas by selectively venting gas at each thruster
 - Primary Vent valve at end of manifold
 - Nominal Vernier Igniter flow keeps line chilled down
 - Vent through vernier valve as necessary
 - Inert liquid nitrogen used in place of liquid oxygen
 - 110 ft. of rigid vacuum-jacketed lines between LN₂ dewar and vacuum chamber represent run length
 - Thruster manifold set up inside vacuum chamber
 - Valve simulators represent thermal mass of RCS thruster valve
 - Heaters placed at each of three injector simulators to examine effect of thermal soak-back from injectors



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WSTF APS Test Article Description

Fuel Accumulator, VJ

- Propellant volume of 4600 in³ ethanol.
- Not currently known if an LH₂ accumulator is necessary or possible

LO₂ Accumulator, VJ

- Propellant volume of 4600 in³ LO₂ at 163 R

Fuel Tank, Vacuum-Jacketed

- Ethanol and LH₂ compatible
- 400 gallon capacity (53.5 ft³)
- 350 MOP

LO₂ Tank, Vacuum-Jacketed

- 400 gallon capacity (53.5 ft³)
- 350 MOP

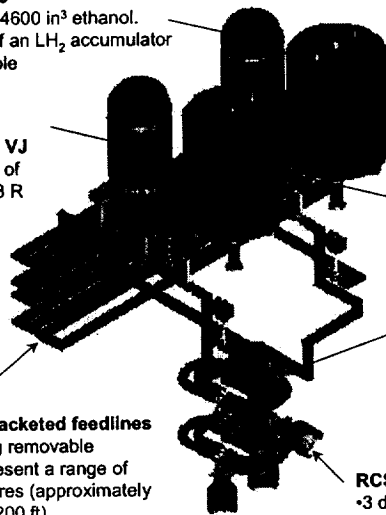
3 Thruster Simulators

- Valves, Orifices, and Feedlines designed to allow simulation of 6 simultaneous RCS engine firings

RCS Engine Stinger

- 3 dual thrust engines
- Separate manifolds manufactured for each engine design

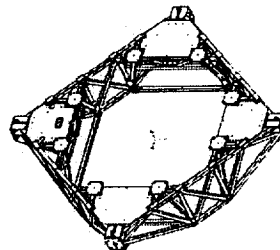
110-ft Vacuum-Jacketed feedlines
 • Assembled using removable segments to represent a range of vehicle architectures (approximately 10, 60, 110, and 200 ft)



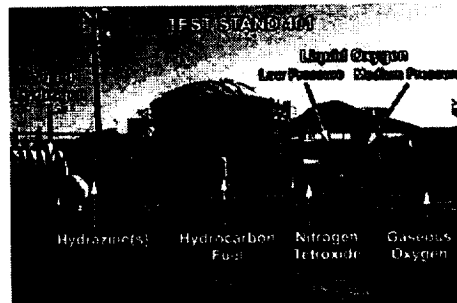
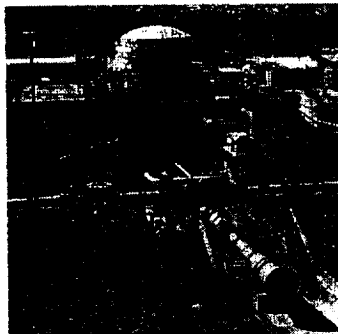
WSTF Test Stand 401



- Use TS-401 and 3 Boiler Steam System
 - >120K ft
 - Maintain > 70Kft during firings
- Use separate area for assembly
- Install on existing Ormond frame



Ormond frame to support test article





On-Orbit Propulsion Project Status



- Initiating Option 1 for TRW and Aerojet Contracts
- Completed Base Testing Objectives
- Risk Reduction Progress on Track
- WSTF Preliminary Design Review Scheduled for June
- Demonstrator Engine Design, Assembly and Test by March 03
- Deliver 3 Prototype Engines to WSTF in Spring 04